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Vol. 28. No. 219. March 1942

THE DEVELOPMENT OF A CAPILLARY VISCOMETER—TO MEASURE VISCOSITIES IN EXCESS OF 10 POISES.

By A. H. Nissan, Ph.D. (Associate Member).

Introduction.

Absolute capillary viscometers exist, capable of yielding high degrees of accuracy when the viscosity of the liquid to be measured is comparatively low. As the viscosity increases, the degree of accuracy decreases, due to the larger effect small errors in the measurements assume in the result. For instance, the change of viscosity with temperature is governed by the general approximate equation

$$\eta = Ae^{B/T}$$

where η = viscosity in poises,
T = absolute temperature,
A and B = constants,

or $$\log_e \eta = \log_e A + \frac{B}{T};$$

i.e., $$B/T = \log_e\left(\frac{\eta}{A}\right). \quad \therefore \frac{d \log_e \eta}{dT} = -\frac{B}{T^2} = -\frac{\log_e (\eta/A)}{T}$$

Hence the magnitude of the change in viscosity with temperature is larger the larger the value of η—a well-established fact. Thus when the value of η is greater than, say, 20 poises, the viscosity may assume 100 per cent. increase on a drop of only 10° C. In other words, even when controlling the temperature of the bath to 0·05° C. the maximum error introduced in the viscosity measurement may be 0·5 per cent., due to temperature variation only. Even this loose analysis illustrates the need for elaborate precautions to be taken with the temperature control and measurement to ensure a reasonably accurate determination of viscosity in the upper ranges.

The general principles of operations taken in the apparatus were as follows: The liquid under investigation was forced through a horizontal straight glass tube while the pressure drop across the tube, the rate of flow of the liquid, and the temperature of the bath were recorded. The pressure was applied by means of compressed air passing through a regulator, and being further controlled by a leak-valve mercury regulator. The level of the outlet of the liquid was kept the same as the level of the inlet by a weir at the outlet and a constant-level arrangement at the inlet. The rate of flow was measured by letting the liquid flow into a reservoir and measuring the rate of flow of the displaced air. A calibrated flow-meter was used for the latter purpose. The temperature of the liquid was controlled and measured by controlling and measuring the temperature of the large bath in which the apparatus (including the flow-meter) was immersed.

Fig. 1 is a photograph of the general layout of the apparatus, before immersion in the bath. A compressor, not shown, filled the cylinder (1), through filter (2), with air under pressure. When the pressure was required,

air was passed through regulator valve (3) and filter (4) to manifold (5). The manifold consisted of valves connecting the air to either a water, inclined-mercury, or vertical-mercury manometer and/or to a steel gauge (6) (the inclined manometer is not seen in the photograph) and to mercury-tube pressure regulator (7). The irregular variations in the pressure due to the regulator were damped by incorporating a packed cylinder between the manifold and mercury regulator (8). The other end of the manifold carried the air through a rubber hose (9) to a brass cylinder (10), which would be clamped over the inlet end of the viscometer—*i.e.*, over the constant-level arrangement (11). This consisted of a reservoir of liquid inverted over the main inlet reservoir of the viscometer and, having two tubes, admitted liquid when the level fell. (Details of the viscometer and viscometer head are in Figs. 3 and 6, respectively.)

The liquid from the reservoir flowed through the tube (12) and over a "sharp-edge" weir (13) into the outlet reservoir (14). Air in (14) was displaced, and its rate of flow could be measured by flow-meter (15), which consisted of a capillary tube and an inclined toluene manometer, which measured the drop of head across the flow-meter capillary. The whole apparatus was immersed in the bath in a similar manner to the way it is shown suspended.

The temperature control is shown in Fig. 2, and will be discussed in a special section.

As the fundamental details of the design employed here are of paramount importance in assessing and controlling the degrees of precision and accuracy of the apparatus, the paper will consist merely of an extended analysis of these details. Thus any desired improvement may be accomplished by tackling the component or factor most readily adaptable to improvement.

The method and purpose of presentation may be better appreciated after the following special analysis:—

The viscosity is obtained from the formula

$$\eta = \frac{\pi P R^4}{8Ql}$$

assuming the temperature is ideally constant and that no need exists to consider kinetic energy and Couette corrections,

where η = viscosity of liquid in poises;
P = pressure differential across the capillary in dynes/sq.cm.;
R = radius of capillary in cm.;
Q = rate of flow of liquid in capillary in c.c./sec.;
l = length of capillary in cm.

By applying the methods of small corrections and approximations, found in every text-book on the Differential Calculus, it is known

$$\delta\eta = \frac{\partial\eta}{\partial P}\delta P + \frac{\partial\eta}{\partial Q}\delta Q + \frac{\partial\eta}{\partial l}\delta l + \frac{\partial\eta}{\partial R}\delta R$$

where $\delta\eta$ = overall error, or correction, in η due to small errors δP in P, δQ in Q, etc.

$\frac{\partial\eta}{\partial P}$ = differential coefficient of η with respect to P, assuming all other factors constant;

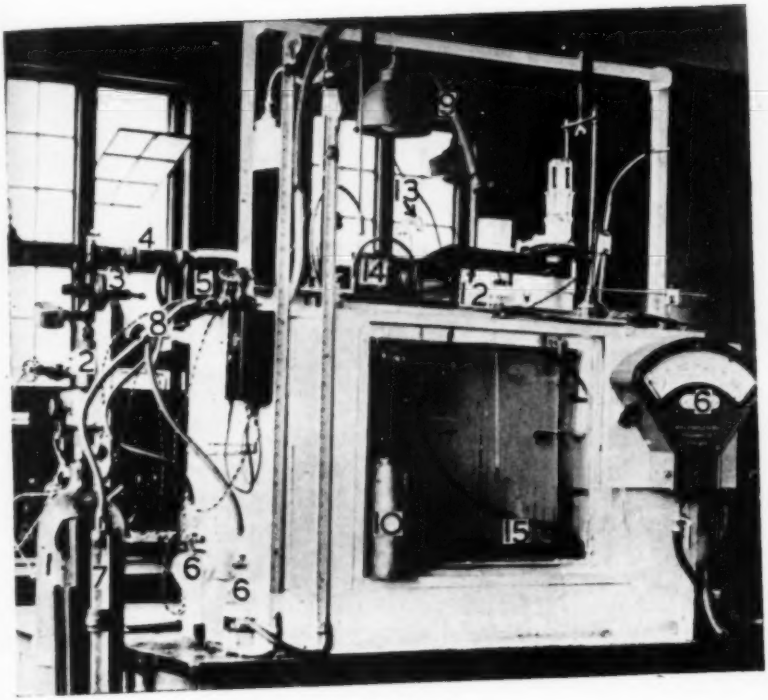

FIG. 1.

[*To face p.* 42.

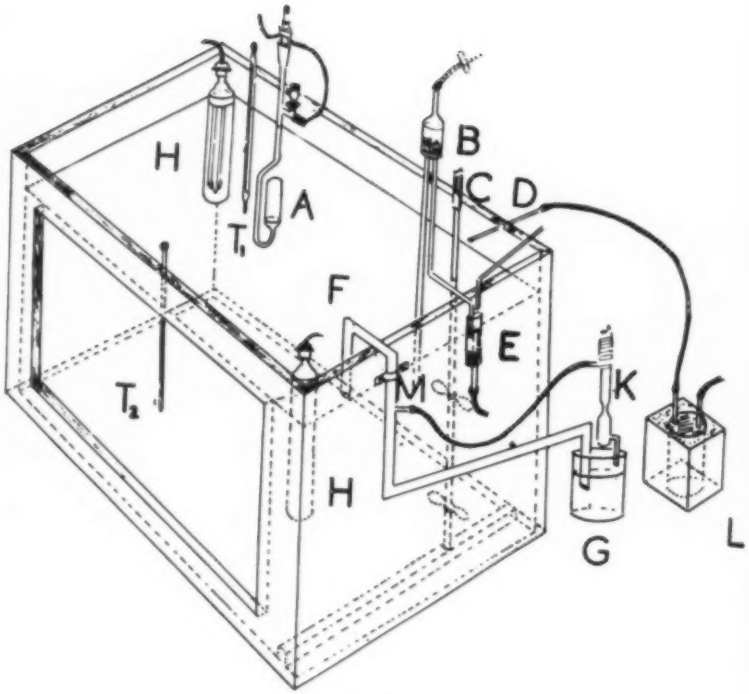

FIG. 2.

Similarly $\frac{\partial\eta}{\partial Q}$, $\frac{\partial\eta}{\partial l}$ and $\frac{\partial\eta}{\partial R}$ are partial differential coefficients of η with respect to Q, l, and R.

$$\therefore \quad \delta\eta = \frac{\pi R^4}{8Ql}\cdot\delta P - \frac{\pi R^4 P}{8Q^2 l}\cdot\delta Q - \frac{\pi R^4 P}{8Ql^2}\cdot\delta l + \frac{\pi R^3 P}{8Ql}\cdot\delta R,$$

$$\text{or} \quad \frac{\delta\eta}{\eta} = \frac{\delta P}{P} - \frac{\delta Q}{Q} - \frac{\delta l}{l} + 4\frac{\delta R}{R}$$

Since the errors in Q and l may be $\pm\,\delta Q$ and $\pm\,\delta l$, respectively, it follows then that

$$\frac{\delta\eta}{\eta} = \left|\frac{\delta P}{P}\right| + \left|\frac{\delta Q}{Q}\right| + \left|\frac{\delta l}{l}\right| + 4\left|\frac{\delta R}{R}\right|,$$

for a maximum limiting value. In other words, the maximum fractional error in viscosity measurement will be the sum of the maximum fractional errors of pressure, rate of flow, and length measurements, plus four times the maximum fractional error in radius measurements. Thus, assuming that each of the four factors was measured with a maximum fractional error of χ

i.e., $\qquad \delta(\phi) = \chi\phi$

where $\qquad \phi =$ factor measured

then the error in viscosity obtained is $7\chi\eta$.

It is important to realize that this analysis is merely a statement of facts, and not an assumption to be proved by experiment. No check determinations of η are necessary if each of the four factors has been measured and controlled, under conditions identical with those existing in viscosity measurement, and checked by measurements to maximum accuracy.

To this analysis must be added the short analysis on temperature effects already discussed. Thus, the subjects of this report were divided into:—

(1) Temperature.
(2) Pressure.
(3) Flow-meter.
(4) Viscometer tube.

Temperature.

A tank of welded steel was constructed, 3 ft. × 2 ft. × 1 ft., with a large glass window in the front. The bottom and sides, excepting the window, were insulated to a thickness of 3 inches by a special asbestos insulating cement contained in a wooden exterior. Two immersion lamp-heaters (*H* in Fig. 2) were used to heat and maintain the temperature of the bath, the heaters being controlled electrically by mercury regulator *A*, actuating a relay switch when the temperature tended to rise.

The regulator operated the two heaters simultaneously. To increase the rate of heating the water in the bath, an independently operated large heater was used during the heating period only.

It was essential to keep the temperature ideally uniform throughout the bath, despite the exposed top and front. Stirrer *C*, rotated by a motor which is not shown, was constructed with two vanes, the upper vane forcing the water upwards and the lower vane downwards. There was no observable

difference in the temperature between any two points at any time. The water then was at a uniform temperature.

Tests were next performed upon the constancy of the temperature. The incorporation of the constant-level arrangement (E, B) maintained the level of the bath constant at all periods and eliminated the trouble of slight temperature rise over long periods. It was only necessary that the tube leading to E let water flow at the rate of a drop a second.

Thus, with these arrangements the temperature of the bath could be maintained constant to $\pm$ 0·01° C. for any period, provided the temperature was at least some 10° C. above room temperature. To be able to work at room or lower temperatures, tube D was incorporated, running fresh water from the tap through a coil in a cooling-bath L to a point just above the upper blades of the stirrer in the bath. In order to keep the level in the bath at a constant height, syphon tube F, of 1-inch iron pipe, was used. To start the syphon, water-pump K was kept running continuously into the water-seal G. The only requirement in constructing this self-operating syphon tube was the condition that the height of the bend in the syphon from the level of the water in the bath should be smaller than the height of the suction tube M from the level of the water-seal in G. Tests showed that flooding was impossible with this arrangement.

With ice surrounding the cooling-coil temperatures of 10° C. below room temperatures could be easily maintained to $\pm$ 0·01° C.

Conclusion on Temperature Control.

The arrangements of Fig. 2 were necessary and sufficient to keep the temperature of the bath (and hence of any object completely submerged in it for a reasonable period),

(1) uniform at all points of the bath;
(2) constant to $\pm$ 0·01° C. maximum deviation.

The lowest temperatures tested were 10° C. when the room temperature was about 20° C., and the highest temperature was 30·00° C.—for fear of the glass cracking.

Assuming the viscosity would change by 100 per cent. per 10° C. rise or fall, then the maximum fractional error,

$$\frac{\delta\eta}{\eta} = \frac{100}{10} \times 0{\cdot}01 = 0{\cdot}1 \text{ per cent.}$$

This error appeared to be reasonable, considering the extra precautions necessary to reduce it, and was accepted as inevitable in measurements of high viscosity coefficients.

Pressure.

Pressure on the inlet end of the viscometer was supplied by a compressor which stored high-pressure air in the cylinder (1) (Fig. 1), and from thence through the manifold to a brass cylinder surrounding the glass reservoir. Air was filtered first at the suction end and then at the outlet of the compressor, then through the inlet to the cylinder (2), and again through tube (3). These filters consisted of brass cylinders containing felt at both inlet and outlets and cotton wool in between. Finally the inlet to the glass reservoir of the apparatus (Figs. 3 and 6) consisted of a small hole in the side,

which was always covered by wrapping a fine silk cloth around it. It was assumed that no solid particle could enter the oil reservoir with these precautions.

To supply air at constant pressure to the viscometer two regulators were used. Regulator (7) was used when the pressure was from 10 cm. water to 50 cm. mercury, by filling the long glass tube with water or mercury up to the necessary level. To eliminate the small inevitable fluctuations of pressure due to the formation and release of bubbles, the brass cylinder (8) was packed with cotton wool and incorporated between the bubbler and the reservoir. With this arrangement the pressure was maintained constant to the accuracy of the reading on the manometer. For higher pressures than 50 cm. of mercury the diaphragm regulator (3) with the damper (4) was found sufficient. Thus the pressure was kept constant to the accuracy of the reading throughout the range deemed necessary for any viscosity measurements likely to be met.

The lower limit to the pressure to be used was set by the accuracy of reading the scale. As a mm. scale was used, 0·25 mm. was considered the highest accuracy of reading possible. Thus, to ensure that the error of reading did not exceed 0·25 per cent., the lowest pressure permissible was 100 mm. of water. Lower pressures could, of course, be used by an inclined water manometer; but it was not considered safe to assume that the fluctuations due to bubbling could be neglected with such low values of pressures without further elaborate precautions. Again, fluctuations in the hydrostatic head in the reservoir itself would assume larger proportional errors with lower values of pressure than 100 mm. water. The vertical water manometer was used, therefore, to record from 100 mm. up to 900 mm. water.

The upper limit for pressure was set by the fact that the variation of viscosity with pressures usually begins to assume a considerable value above five atmospheres. Thus, the limit was set at 300 cm. mercury, and was considered safe. To measure the higher pressures a steel gauge was used—after detailed study of its behaviour was made.

For intermediate pressures, an inclined mercury manometer was used to measure pressures between 60 and 150 mm. of mercury, and a vertical manometer for measurements between 130 and 900 mm. mercury. The manometers and gauge thus overlapped to ensure concordant readings when the readings were transferred from one to the other.

In incorporating and using the manometer, each point of the analysis of the sources of error enumerated by Barr [1] was studied and all necessary precautions taken.

The back pressure exerted by the flow-meter on the outlet of the viscometer had to be considered. The inclination of the flow-meter manometer was 1 : 16·6. The liquid used was toluene. The correction applied was equal to $(0{\cdot}056x)$ mm. water, where x was the reading in mm. on the flow-meter.

The steel gauge was calibrated by the makers in cm. of mercury. When it was tested, however, even at relatively low pressures, a great error was evident. Setting the zero point to read correctly on the gauge, it was found that the error in reading was progressively greater; thus, the gauge had greatest error where it was mostly needed—*i.e.*, at higher pressures. The artifice was therefore followed of setting it to read correctly at 100 cm.

mercury and calibrating it over the entire range of 50–300 cm. mercury. Since the gauge will not be used below 90 cm., this arrangement made it possible to have low proportional errors both where the gauge was mostly used (90–150 cm.) and also where the higher values of pressures made the bigger errors at the upper range proportionately smaller. Calibration shows that whilst the magnitude of the difference between the gauge reading and the correct pressure is considerable between 200 and 300 cm., this difference is practically constant—to 0·5 per cent. The curves for the various calibrations were plotted on one chart of 50 × 50 inches, and it was seen that all the points fell substantially on one curve. The calibration was made against an absolute mercury manometer, 3 metres length, on different days and by two persons.

It was found that, provided a calibration chart be constructed from a great many points of calibration and always used in conjunction with the gauge, the error of pressure reading need not be greater than 1 per cent., taking all sources of errors into account.

A similar conclusion has been reached with regard to the water, inclined-mercury, and vertical-mercury manometers when readings were taken on all three simultaneously and compared with each other—*i.e.*, maximum error introduced in the viscosity measurements due to all causes of errors in the pressure measurement shall not be greater than 1 per cent.

In viscosity measurement by this method the greatest cause for error is in regulating and measuring the pressure. The error due to imperfect pressure regulation and measurement is ten times as great as the error due to thermal sources. Thus, up to this point, it cannot be expected that the method can give a viscosity measurement with a greater accuracy than 1 per cent., even if all other sources of discrepancies were completely eliminated. This explains the need for elaborate precautions to be taken in the temperature regulation and measurement and flow-meter construction, calibration, and use. To have reduced the error in the pressure regulation and measurement to less than a maximum of 1 per cent. would have meant the incorporation of unwieldy and intricate refinements, which would not be compatible with the nature and scope of the work.

Flow-Meter.

Fig. 3 shows the arrangement of the flow-meter, which was completely immersed in the bath. The displaced air, after going through a water-trap, passes through the capillary to the atmosphere. The pressure drop across the capillary is read on the toluene inclined manometer. Benzene was tried first, but it was found to evaporate rapidly, necessitating frequent refilling. Toluene was found an ideal liquid for the purpose.

The flow-meter was rigidly connected to a brass frame, which was suspended by two brass rods fixed rigidly to the side of the tank. By experiment it was proved that the setting of the manometer was the same in every case, when the flow-meter was taken out of the bath, emptied, dried, and refilled. By this arrangement both the inclination and the temperature of the flow-meter were therefore accurately controlled. The air flowing through the instrument was always 100 per cent. saturated with water vapour. Analar toluene was used throughout from one bottle. No change in the calibration curve could be detected, even when " technically pure "

toluene was tried. Thus both the material flowing and the fluid used for measuring the pressure drop were of constant properties.

To derive the curve of calibration it was decided to calibrate the flow-meter under identical conditions which would exist in viscosity measurement. The set of experiments undertaken are outlined here.

Fig. 4 shows the calibrating arrangement. The purpose was to provide a constant rate of flow of air from an apparatus similar to the viscometer through the flow-meter at temperatures which could be accurately measured and kept constant. The calibrating apparatus consisted of tube *A* withdrawing water from the bath and some 3 inches below the surface from a space included in tube *B*, which was open at both ends. Thus the water

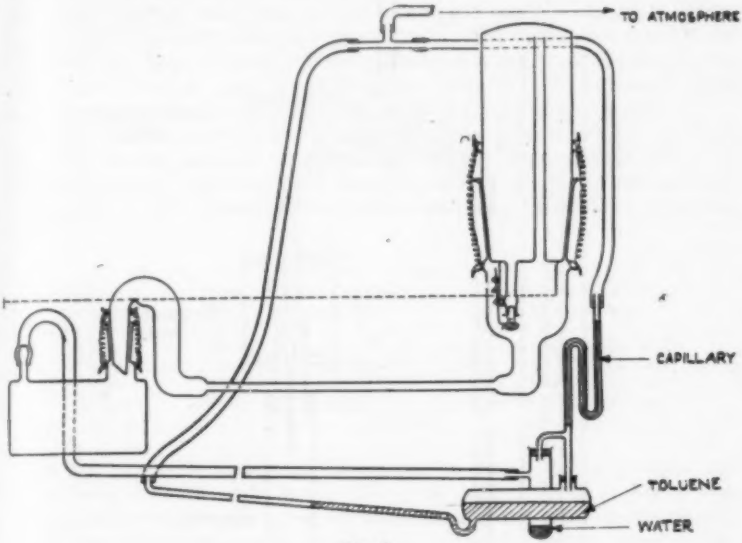

FIG. 3.

withdrawn was clean bath-water at the temperature of the bath. By using the bath-water, a constant level for inlet pressure was assured. At the time of taking the reading the stirrer was stopped momentarily to provide a steady head. This practice was therefore followed in viscosity measurements.

The water was withdrawn from *A* through syphon *C* into the nozzle *D*, which discharged into an N.P.L. calibrated burette *E*. The burette had a capacity of 10 c.c. The total error of the burette capacity was less than 0·2 per cent. The air displaced passed through tube *F* to the flow-meter. By raising or lowering the outlet level of the nozzle and fixing it vertically at any one position, the head driving the water through was varied, and hence the rate of the flow of water was varied. A clip was placed on the rubber tubing leading to the nozzle to start or stop the flow by the syphon action.

Experiments were made to determine whether the flow was constant or

not. Starting the flow below the 10-c.c. mark, the time was taken as zero at 10-c.c. mark, and read at every 1-c.c. mark, the watch being stopped at the zero-c.c. mark. The rate of flow was then calculated over intervals of time taken to fill 5, 6, 7, 8, 9, and 10 c.c., respectively, starting at different marks. An unsteadiness of flow would be revealed. It was not considered sufficient that the flow-meter registered a steady head, as the sensitivity of the flow-meter was unknown.

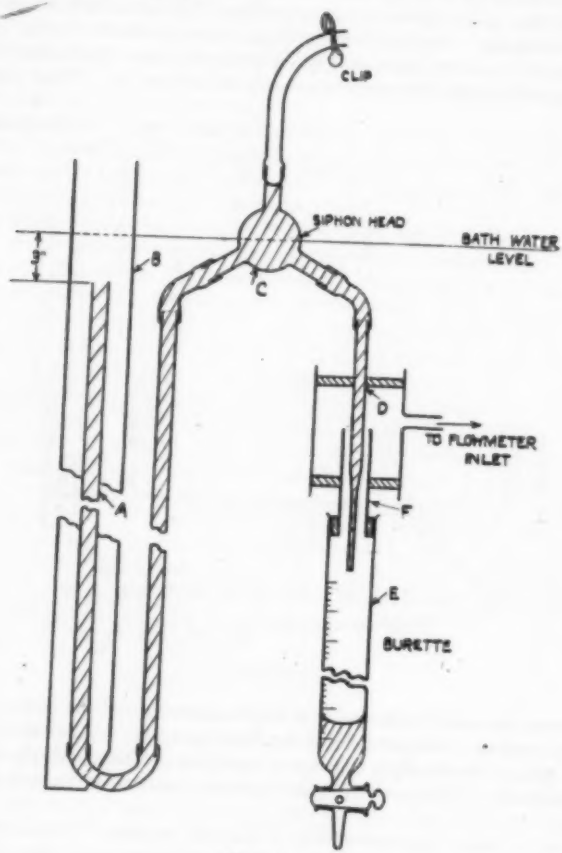

FIG. 4.

It was found that for volumes filled greater than 8 c.c. the flow results were constant. Hence it was concluded that the deviation observed over the smaller volumes filled were due to imperfect observations, and not to the unsteady nature of the flow of water in the syphon. It was also made obvious that taking the time for 10 c.c. to be filled up would yield more accurate results, or at least as accurate, as Gauss's method for averaging the rate of flow for different intervals. Hence, in all further experiments

the time to fill 10 c.c. was measured by starting and stopping the stop-watch, and an average of a number of such measurements was considered to be the time of flow of 10 c.c. of air through the flow-meter.

When points were plotted on a graph having " rate of flow, c.c." for an abscissa and " head lost " for ordinate, these were found to lie on a straight line for each one temperature. The scale of the chart was large (50 × 50 inches) in order to plot the points with an accuracy at least equal to those of the readings.

Similar results obtained afterwards yielded points which fell on the same line within 0·5 per cent. To make certain that the results were reproducible, the toluene was evaporated under vacuum at 30·00° C., the flow-meter removed from the bath, and the joint between the reservoir of the flow-meter and capillary tube broken. Fresh toluene was put in, and the flow-meter assembled and fixed again in the bath. The flow-meter was left for 3 hours in the bath at 30·00° C., the calibrating assembly was joined to it, the syphon started, and the flow-meter completely recalibrated. The calibration curves were straight lines, and fell on the previous ones.

All the straight lines passed through the origin. Therefore one point on each line, passing through the maximum number of points determined at that temperature, represents the characteristic of the flow-meter at that temperature. The following four points were thus derived for the flow-meter :—

Temperature, ° C.	" Head lost."	Rate of flow, c.c./sec.	Characteristics of flow-meter at that temperature.
15·00	250·0	0·1115	1 div. = 0·0004460 c.c./sec.
20·00	250·0	0·1095	1 div. = 0·0004380 c.c./sec.
25·00	250·0	0·1079	1 div. = 0·0004316 c.c./sec.
30·00	250·0	0·1057	1 div. = 0·0004228 c.c./sec.

Fig. 5 is a plot of these four points, and it is seen that a straight line passes fairly well through them. Thus, the straight line in Fig. 5 was taken to represent the characteristic of the flow-meter in preference to any of the four curves obtained individually. The difference between the straight line and the individual points obtained is maximum at 25° C., where it is 9 in 4310 or 0·2 per cent.

A check calibration at 20·00° C. gave a maximum deviation from the value obtained from the line of Fig. 5 of 0·48 per cent. and an average deviation of 0·35 per cent.

Hence, it was accepted that with the arrangements and precautions described for the temperature, pressure, and flow-meter employed in this apparatus, a maximum error of 1·6 per cent. may appear in viscosity measurements, this maximum error being independent of the viscometer itself. In other words, even if the viscometer tube and reservoirs contributed no error at all, a viscosity measurement taken by the apparatus might be 1·6 per cent. in error. Of course, the average error will be of a smaller dimension; as in the analytical method of finding the maximum possible error, the worst conditions are assumed to be operating—*i.e.*, the errors are additive. In practice, there is a tendency for the errors to cancel each other to a great extent.

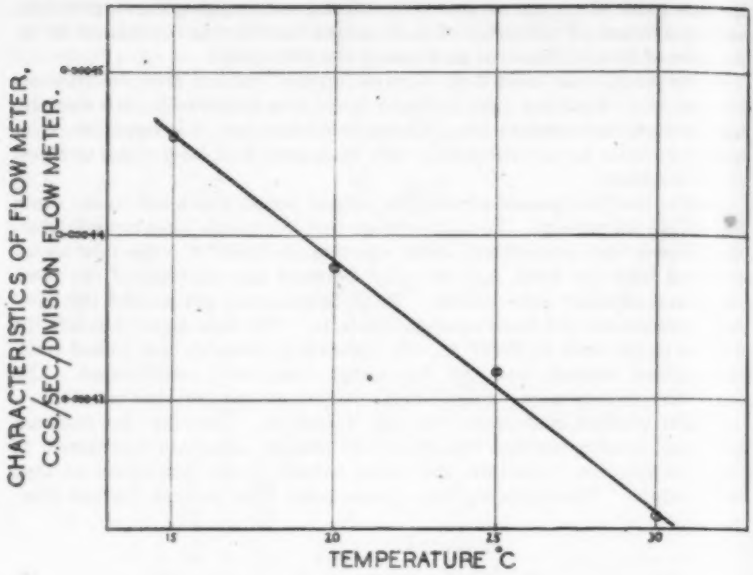

FIG. 5.

THE VISCOMETER TUBE.

The viscometer used is shown in Fig. 3. The essential parts of a viscometer of this type are : (1) a reservoir for holding liquid at the inlet of the tube, (2) a long, narrow tube, and (3) a reservoir for holding liquid at the exit end of the tube. The last part was made to hold 600 c.c. of liquid and to have an inlet for the liquid and an outlet for the displaced air. The conical end of the viscometer tube went into an enlarged space, so that the liquid went directly into the reservoir. The air outlet was connected to the flow-meter inlet via a water-trap, which also acted to saturate the air with water vapour at all times, and thus duplicate the calibration conditions.

The viscometer tube itself was designed to be used in measuring the viscosity of liquids possessing a coefficient of viscosity ranging between 10 and 750 poises. The limitations imposed were : (1) no greater pressure than 300 cm. mercury should be required to produce a rate of flow of 0·01 to 0·25 c.c. per second, with the most viscous liquid to be used; (2) no lower pressure than 100 mm. water should be required to produce rate of flow sufficiently low to be measured by the flow-meter (0·01–0·25 c.c. per second) when the lightest liquids are studied, of approximately 10 poises; (3) the ratio of length to radius of tube should be approximately 100. After trial calculations have been made a tube of 250 mm. length and 0·26 mm. radius was specified.

With this tube and rates of flow limited to 0·01 and 0·25 c.c. per second, it became impossible to have turbulent flow in the tube even if water was used as the flowing medium—of one centipoise viscosity.

Again, considering the kinetic energy correction, it was found that it was negligible.

This fact is important, as the value of m varies with the type of approach and exit ends of the tube. With the conclusion reached it became immaterial whether square or bell-shaped ends should be incorporated in the tube, provided the length of the tube was sufficiently determinable by direct measurements.

The Couette correction for end effects was the next factor considered. This is usually incorporated as an added length to the actual length of the tube, the correction being a certain ratio of the radius, thus

$$l' = l + na$$

where l' = corrected length to be incorporated in the Poiseuille formula, cm.

l = actual length of tube, cm.

a = radius of tube, cm.

n = a factor.

The correction amounted to some 0·6 per cent. of the length, and hence could not be neglected; this necessitated, however, the direct measurements of the tube. Certain other considerations made it more appropriate to take the length as measured and assume the correction to be incorporated in the value of the radius. The method adopted here was to measure accurately the length of the tube, and then to calibrate the tube with oil, and thus obtain a mean hydraulic radius which would incorporate all corrections automatically. The reasons for this procedure will be apparent from the following discussion.

The two chief items to be considered in designing the inlet reservoir and the outlet end of the viscometer tube were: (1) the hydrostatic head and (2) surface-tension effects. These were both solved in a practical manner by incorporating a constant head arrangement at the inlet and a relatively sharp weir at the outlet. Thus by filling the viscometer reservoir and suspending the entire assembly on three adjustable rods, the levels in the inlet and outlet of the tube were made the same, and hence any surface tension effect was eliminated. This was checked by suspending the viscometer and adjusting the lengths of the rods so that no flow took place when no pressure was applied. By closing the outlet end of the flow-meter capillary, the toluene inclined manometer acted as a most sensitive leak-detector. Thus, by observing that not the slightest increase in pressure in the outlet reservoir took place, the viscometer was assumed to have the two levels at the inlet and outlet the same. The level of the liquid at the weir was visually observed.

The final difficulty was to design a "constant"-head arrangement which gave no important fluctuations. After some six attempts on designs similar to the present one, the arrangement shown was found to be entirely satisfactory. Fig. 6 is a detailed diagram of this arrangement.

Measuring a radius of 0·26-cm. tube accurately to the fourth significant figure was impracticable with the usual mercury-thread procedure, requiring much more elaborate methods. Further, even this constant-head arrangement, which gave no signs of fluctuation in pressure at the inlet, must of necessity provide a slightly fluctuating head. These facts were responsible for calibrating the tube with a liquid of a known viscosity. Thus, all the small errors would be combined into one, and be taken into consideration

automatically. Hence, it was decided to take the N.P.L. viscometry as a standard, and, by using an oil tested by the National Physical Laboratory as a calibrating oil, find the overall accuracy of the apparatus. The overall maximum error minus 1·6 per cent. gives the maximum error due to fluctuation in head and other incidental errors.

The following experiments will illustrate the use and accuracy of the viscometer.

The viscometer was cleaned with cleaning acid, then washed with water, and finally with absolute alcohol and drained dry. By applying suction to the outlet end of the reservoir, air was sucked in through a fine silk cloth, which covered the air inlet to the viscometer (*see* Fig. 6). The

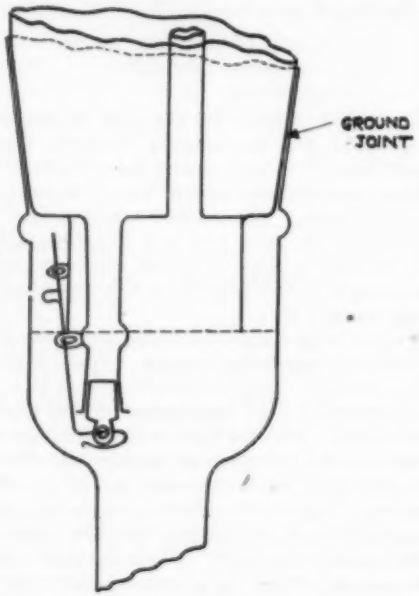

FIG. 6.

viscometer was dried with air for a period of 24 hours. (No smell of alcohol could be observed after that period.) The viscometer was then suspended over the upper cross-bar of the bath (as shown in Fig. 1), and the outlet connected to a two-way tap, making connection to the atmosphere or the flow-meter inlet as necessary. The upper cylinder of the inlet reservoir was removed, the tap opened to the atmosphere, and air-free oil poured into the inlet reservoir, slowly, to avoid trapping air-bubbles in the viscometer tube, until the oil was nearly at the level of the weir.

The ground-glass stopper of the upper portion of the constant-head arrangement was removed and oil poured through the large entry tube until the cylinder was almost completely filled. The ground stopper was then replaced and the cylinder inverted till the oil drained from both the long, enclosed tube and the external wide tube. The cylinder was replaced over

the reservoir, and the springs attached to the hooks; thus, the upper and lower portions of the constant-head arrangement were assembled. A short, stout wire was then thrust through the hole in the side of the reservoir and engaged the loop in the wire holding the stopper. With a thrust downwards, the stopper was removed from its socket, and oil flowed to the reservoir until the level rose to the edge of the wide outer tube. Flow stopped at this point.

When a thick oil is used, it is proposed not to use the constant-head arrangement, but to plug the hole in the reservoir and fill the reservoir to the top. As higher pressures will be required, it is only necessary to take the mean hydrostatic head into account and apply the appropriate corrections.

A silk cloth was wrapped around the reservoir to filter the air going through the hole, and a rubber band kept the cloth in place.

The brass cylinder was bolted down on a hard rubber washer, the joint between the glass apparatus and the brass plate having been permanently sealed by a stuffing-box arrangement using rubber washers, and with wax on the upper side. Connections were then made between high-pressure hose and the top of the brass cylinder. All this time the apparatus had the surface of the oil inside the inlet reservoir at a lower level than the weir.

When the apparatus was completely assembled it was lowered to the lower cross-bar and bolted down by two butterfly nuts, keeping the weir still higher than the level of the oil. The bath was maintained at the temperature required. The air expanded directly to the atmosphere at first; then the tap was turned to connect the outlet reservoir with the flow-meter. The apparatus was left in the bath for 1 hour, so that both the temperature of the oil and the air and the saturation of the air with water vapour were as required.

The next step was to level the apparatus. This was done by tilting the tube, through the use of the suspending rods as levelling screws, until oil began to flow over the weir, then tilting it back until the oil just ceased to flow, and yet the oil was still at the weir. By stopping the outlet of the air capillary on the flow-meter with a rubber clip, the toluene manometer indicated even very minute rates of flow. When there was no evidence of flow, it was considered that surface-tension effects had been fully balanced, any flow resulting therefrom being too small to affect the results. Similarly, it was considered that the level of the oil both at the inlet and outlet was sufficiently the same not to introduce any measurable error.

When all these preparations were made, readings were taken for pressure of the air and rate of flow on the flow-meter. The stirrer was stopped for the reading to be taken in a quiescent bath. The temperature was constantly checked. Previous tests showed that the rate of cooling of the bath was far too slow to affect the temperature over the period of reading.

Oil having viscosity of 14·6 poises at 21·1° C.
Temperature of the bath 21·10° C. throughout the experiment.
Temperature of the laboratory—18·0° C.
Zero point on water manometer—49·0 mm.
Zero point on flow-meter—407·0.
Characteristics of flow-meter at 21·1° C.—0·0004369 c.c./sec./division.

TABLE I.

No.	Pressure reading, mm. H_2O.	Uncorrected pressure, mm. water.	Flowmeter reading.	Flowmeter "head."	Back pressure, mm. water.	Corrected pressure, mm. water.	Rate of flow, (c.c./sec) $\times 10^{-2}$.
1	140	91	311	96	5·4	85·6	4·20
2	150	101	296	111	6·2	94·8	4·85
3	154	105	294	113	6·3	98·7	4·94
4	162	113	281	126	7·1	105·9	5·50
5	162	113	283	124	7·0	106·0	5·41
6	170	121	273	134	7·5	113·5	5·85
7	170	121	274	133	7·5	113·5	5·81
8	190	141	253	154	8·6	132·4	6·72
9	190	150	242	165	9·2	140·8	7·20
10	200	151	242	165	9·2	141·8	7·20
11	210	161	233	174	9·7	150·3	7·60
12	220	171	219	188	10·5	160·5	8·21

For Newtonian flow all that is required to obtain the characteristic of the apparatus is to calculate k, a constant by which the ratio of pressure to rate of flow is multiplied to give the viscosity of the fluid. Thus let

$$\eta = k \cdot \frac{P}{Q} \text{ or } k = \eta \frac{Q}{P}$$

where η = viscosity in poises.
P = pressures in mm. water.
Q = rate of flow (c.c. sec.) 10^{-2}.

The following set of values of k are then obtained :—

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
0·717	0·748	0·730	0·757	0·746	0·752	0·747	0·741	0·748	0·743	0·737	0·747

Neglecting the first point, as the pressure was far too low for accurate reading (100 being a minimum), the average value for k is 0·745, with a maximum error of approximately 2 per cent. Thus, the oil was Newtonian, and the precision of the apparatus is of about 2 per cent. maximum error for any one single reading. For Newtonian liquids the error would be considerably lower, as an average might be obtained for a whole set of points falling on a straight line. For non-Newtonian flow, however, the points for a rate of shear-shearing stress diagram fall on a curve, and hence each point has to be taken to a greater extent than in the former case as individually important.

To calculate the radius, the average value of k was taken and introduced in the formula

$$\frac{R^4}{l} = \frac{8Q\eta}{\pi P} = 0{\cdot}0001934$$

where Q = rate of flow in c.c./sec.
η = viscosity in poises.
P = pressure in dynes/sq. cm.

l was measured, and found to be 25·00 $\pm$ 0·02 cm. Hence R^4 is equal to 0·004835 cm., and R becomes 0·2636 cm.

Two types of errors have to be studied here :—

(1) The errors due to fluctuation in the hydrostatic head, surface-tension effects, and general irregularities in the design or manipulation of the viscometer tube and reservoirs. These errors are independent of the value of the viscosity of the test oil. It can be estimated from the maximum variations of the twelve determinations of k from the mean value, or simply from the maximum variation of the individual points of a plot of the rate of flow *vs.* pressure from the straight line passing through the mean position of these points (Fig. 7). This error is seen to be 2 per cent. Since it is possible that 1·6 per cent. was due to irregularities in temperature, pressure, and flow-meter readings, then the viscometer is responsible for at least 0·4 per cent. error.

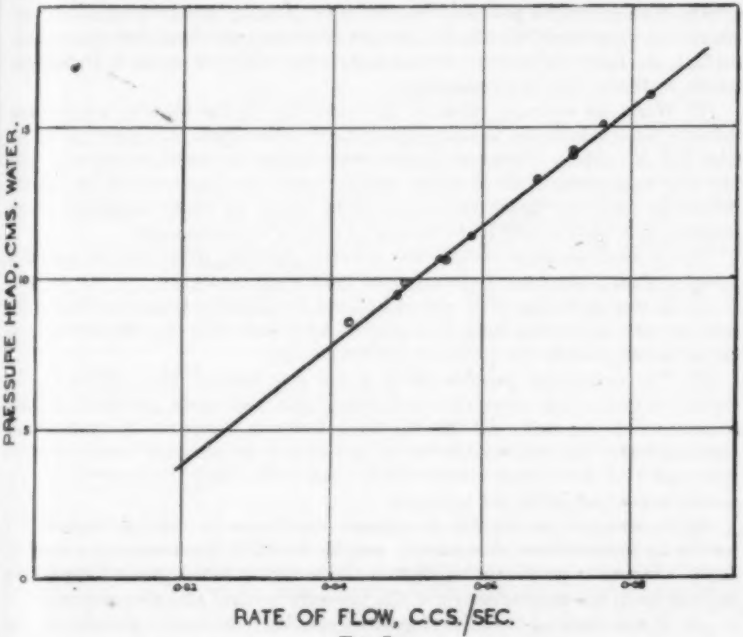

FIG. 7.

(2) The actual value of k to be used in measuring the viscosity of Newtonian liquids and of R for the calculation of rates of shear and shearing stresses at the glass/oil interface is affected by the value of the viscosity of the calibrating oil and by the errors of the present viscometer. It is true that, since the figure 14·6 poises was taken from a National Physical Calibration, it is accurate to the limits of the present apparatus. Nevertheless, it has been decided as a good policy to doubt this figure, in case the cleaning of the apparatus, for instance, has not been complete, and also in case the setting of the apparatus has an influence over the results obtained.

Hence it was decided to empty, clean, and refill the apparatus and set it up and measure the viscosity of an N.P.L. calibrated oil at 17·5° C. This was performed in exactly the same manner as employed before in obtaining the twelve results for the calculation of k and R.

The following data were supplied from experiment :—

Viscosity of oil at 17·50° C. . .	19·4 poises.
Temperature of bath . . .	17·50° C. throughout the experiment.
Temperature of the laboratory .	19·0° C.

The results of twenty experiments were that (1) summation of errors was zero, (2) maximum values of individual errors were $\pm$ 1·6 per cent.

Conclusions.

The following conclusions became evident :—

(1) A value of 0·745 for k, the constant of the instrument, gave the viscosity of an oil of 19·4 poises correct to 1·6 per cent. in twenty determinations. Since the value of 0·745 was an average of twelve previous determinations, in fact, the figure 0·745 gave the viscosity correctly, to 2 per cent. maximum error, in thirty-two determinations.

(2) When an average value of the viscosity of the oil was taken from twenty determinations, the average did not differ from the figure given by the N.P.L. Thus, if average values were taken for the viscosity of an oil by this instrument, the average might safely be assumed to be nearly identical with the figure which would be given by other absolute viscometers, provided a sufficient number of results were obtained.

(3) In such average results the average did not differ by an amount greater than 2 per cent. from any one individual result.

(4) It was seen that if R was calculated from the average results of the last twenty determinations, it would be identical with the value obtained as an average from the previous twelve results.

(5) The maximum possible error which was beyond the control of the operator using this apparatus and taking the constants provided in this report was 2 per cent. Of this the irregularity in temperature control and measurement was responsible for 0·1 per cent.; in pressure control for 1·0 per cent.; in flow-meter control for 0·5 per cent.; and therefore in hydrostatic head control for 0·4 per cent.

(6) It was not practicable to change conditions in order to reduce the errors in temperature, flow-meter, and hydrostatic head control considerably. Hence any attempt to improve the accuracy of the present apparatus should be in the improvement of the pressure control and measurement.

(7) It was realized that the viscosities studied here were conducive to the maximum percentage errors, as the pressure readings were low, and therefore the effects of any variation in the hydrostatic head in the inlet reservoir assumed its maximum degree of importance. Even when the viscosity was raised from 14·6 to 19·4 poises, the maximum error dropped from 2 to 1·6 per cent.; the small variation in hydrostatic head became less important. Thus, with higher viscosities, necessitating pressures greater than, say, 100 cm. water, it is believed that the constant-head arrangement would function with a negligible difference from the ideal, and the total error would become 1·5 per cent. at its maximum.

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Reference.

[1] Barr, G., "A Monograph of Viscosity." Oxford University Press. (1931.)

PARLIAMENTARY AND SCIENTIFIC COMMITTEE.

LUNCHEON.

3rd February, 1942.

A LUNCHEON of the Parliamentary and Scientific Committee was held at the Savoy Hotel, London, on Tuesday, 3rd February, 1942. The Institute of Petroleum, which is a supporting member of the Committee, was represented at the Luncheon by Mr. C. Dalley, Mr. T. Dewhurst, Dr. A. E. Dunstan, Dr. E. R. Redgrove, and Mr. A. E. Evans (members of Council). We reproduce below two speeches of particular interest to scientists, by Lord Hankey, G.C.B., G.C.M.G., and Sir Henry T. Tizard, K.C.B., F.R.S. (Hon. Member), respectively.

The RT. HON. LORD HANKEY.

I have been asked to propose the Toast of "Science." In these parlous times this means Science in War. That is a vast subject, the more so because in war the financial limitations which hamper science in times of peace are relaxed, and funds become available on an almost unlimited scale. The extent of present scientific activity may be judged from a note which my friend Captain Plugge was good enough to send me about your Committee's work. Referring to wartime difficulties the note says:

> "The technicians and scientists are so immersed in war work that they have little time for political activity."

That is the bare truth. In spite of what has been said to the contrary, most of our scientists have been harnessed into war work; perhaps I should say have harnessed themselves, because I know of no part of the community which has responded more readily to their country's call. The problem to-day is not to find jobs for scientists, but scientists for jobs.

I suppose I owe the honour of proposing this Toast to my association with the Scientific Advisory Committee, the Engineering Advisory Committee, and the Technical Personnel Committee, devoted to the provision and training of men and women for radiolocation and other technical equipment for the Services, for research and for industry. I could not attempt to describe the work of these bodies in the few minutes at my disposal.

I recall, however, that when the Scientific Advisory Committee was set up, there was some discussion, in which your committee took a part, as to whether it should include representatives of applied science. The Government decided to confine it to representatives of pure science, partly in order to limit the numbers in the interest of efficiency. A few months later, however, the Engineering Committee was set up to advise the Government on that branch of applied science. Both bodies have found plenty to do within their respective spheres. But they work in close association, and from time to time questions crop up in the borderland between pure science and applied science. In view of your interest in the matter, you may like to hear that we deal with these cases by *ad hoc* joint conferences composed of appropriate members of both bodies, often with the aid of best scientists or engineers from outside our own membership. We seek the best available scientific help.

We have no difficulty in obtaining it, for we receive enthusiastic co-operation from the numerous scientific and research organizations of Government Departments, from the Royal Society, the great Engineering Institutions, Universities, and independent scientific workers. I take this opportunity to place on record our indebtedness to the whole scientific world in this respect.

We have also arranged for ever-increasing co-operation with the Dominions and the United States of America, with its vast scientific resources. The United States, Canada, and Australia have established scientific agencies in this country, and there is a constant stream of individual scientists and of scientific information between this country and America and the Dominions, so as to ensure a united effort in research development and the application of science. They have also given us substantial aid with technical personnel.

I am told that some enthusiasts maintain that the Government itself ought to

be run by scientists; that, if that were the case, we should soon win the war; or, as some would have it, that there would have been no war. That is going too far. There is, of course, a science of war and a science of government, but in both there is a good deal more than that.

War is sometimes referred to as an art. It is also called "the sport of kings"—perhaps we ought to say Dictators to-day. Whether it is itself a science or an art, however, war, with its nice calculations of fleets, armies, and air forces, each with its own ramifications, with its problems of time, space, speed, striking power, protection, and training, to say nothing of production, agriculture, food supplies, health and man-power—all this, I say, requires the co-operation of scientists at every phase.

So anxious are the Departments for first-class scientists that my friend, Sir Henry Tizard, is a member not only of the Air Council, but also of the Aircraft Supply Council. All three Fighting Services are tremendously science-conscious. Scientists are being employed more and more, even in the operational side of their work; not only individual scientists, but, what is even more important, teams of scientists, some of which I have myself seen at work. In addition, our Universities and Technical Colleges are giving intensive scientific training to great numbers of men and women to operate the mass of scientific war apparatus that Industry is producing.

This reliance on science in our hour of need to-day is, I believe, going to have a tremendous effect on statesmen and officials after the war.

So far none of my scientific friends, neither Sir William Bragg, the late President of the Royal Society, nor Sir Henry Dale, the present President, nor the presidents of any of the great Engineering Institutions, have evinced to me the slightest desire to take Mr. Churchill's place !! In these days, however, not the least important of the functions of government is to place science on the war map. That is what we are doing our utmost to accomplish, and you will agree that it is essential to victory.

Sir Henry T. Tizard.

Looking at things as a whole, no one can deny that the influence of science is now greater than it has ever been, and that the present Government and Parliament attach a value to the help and guidance of scientists that no previous Parliaments have ever done. Lord Hankey has already told you something of the work of the Scientific Committees over which he presides. There are many more such Committees that I could mention. There is hardly a phase of the national life now with which scientists are not associated. In fact, a fighting friend of mine said that he could hardly walk in any direction in this war without tumbling over a scientist who had got in the way. In the Royal Air Force, where the concentration of scientists is perhaps greatest, they have a pet name for them. They call them "Boffins." Why, I do not know. I said to a young friend of mine in the Air Force, "Why do you call scientists 'Boffins'?" He said, "I don't know. What else would you call them?"

And then, what previous Prime Minister of England ever had a scientific adviser continually at his elbow? He is not the only Minister who has a scientific adviser. Even Commanders-in-Chief have them, as General Pile, who is here, would blushingly admit.

I am sure that it has not escaped the notice of those members of your Committee who are not scientists that we scientists are a very critical lot. We see with the greatest clearness the shortcomings of other people! Indeed, we are brought up to be critical; it is part of our education to accept things only on evidence, and not merely on the unsupported authority of older men. There is no such thing in the scientific world as authority based merely on position and seniority. It is true that we are brought up to be constructive critics, but human nature being what it is, I will not claim that we are always constructive, though we generally try to be. And let me let you into a secret. We scientists and scientific advisers do not always agree among ourselves. Your quick wit and ready perception will at once lead you to deduce that sometimes some scientists are wrong. This profound fact should always be borne in mind by your Committee.

What is the general result of this widespread intrusion of scientists into the affairs of the war? Let me try to explain my views with the help of an analogy. There are not so many people who really understand the methods and processes of science, but we all think we know a good deal about war. Science, like war, has its strategy and its tactics. Tactics come in when the plan is settled, the task decided, and the problem set: and in science—as in war—success in tactics depends on good com-

mand, good organization, an adequate amount of up-to-date equipment, and an adequate amount of highly trained men. Judged in this way, the tactical strength of science in this country is very great. There are many well-run and well-equipped research and experimental establishments up and down the country under direct or indirect Government control or under independent control. Above all, thanks to the progressive policy of education in the last twenty years, and also, I like to think, to the innate qualities of our race, there is a large supply of able young men who are now rendering, by their scientific work, great service to the State.

I fancy that the amount and quality of the scientific and technical ability available in this country has surprised even some of the older generation of scientists. It has certainly surprised our foreign friends and foes. Perhaps it was because peace-time conditions in this country did not give these young men a real chance to show what they were worth. If so, we have a problem to deal with after the war. Or perhaps it is because, as a nation, we have a habit of keeping our best goods away from the shop-windows. I remember a well-known aeronautical engineer, who came over to this country from the United States shortly before the war. He was very depressed at what he thought was the state of aeronautical science in this country. Our science was bad; our engineering was bad; and our design was bad. Being a real friend of this country, he expressed his gloom to me. He thought we were a long way behind Germany, let alone America. He went out of his way to give his views to people in more influential positions. About eighteen months ago I met him again, in the United States. I reminded him of our conversation, and he said, with that impulsive generosity which we find so attractive in Americans, "Oh, don't remind me about it; I take it all back."

My considered opinion is that, so far as the tactics of science are concerned, we have nothing to fear in comparison with any other nation.

So far as the strategy of science is concerned, I am not so confident. Much has been done to improve it, but much remains to be done. The strategy of science is again similar to that of war. The strategy of pure science is to attack at the weakest spot of the barrier to knowledge. The secret of science is to ask the right question, and it is the choice of the problem, more than anything else, that marks the man of genius in the scientific world. The strategy of science applied to war is to attack at the point where the dividends are greatest in results in relation to the effort. Our tactical strength is great, but it is not unlimited. We cannot afford to dissipate our efforts over things that do not matter or do not matter much, and we must remember, too, that any technical advance, to have a decisive effect in war, makes big demands on the productive capacity of the country. All this you may say is common-sense; but it is not common-sense that is very apparent. Few people have any idea of the spate of inventions that have to be considered and dealt with in the Service Departments. Most of them are, of course, worthless, and just waste time. I have been told that only one in every thousand patents has any likelihood of being used and only one in every ten thousand is of any real value. The official in the Patent Office is in a happy position. All he has to do is to satisfy himself that any suggestion, however stupid, has never been made before, and then charge the individual who made it a fee for the privilege of having it registered, and there the business ends. How the individuals in Government Departments who have to deal with inventions in war would rejoice if they were in the same happy position! But it is not the worthless inventions that are the real trouble. The real trouble and waste of time are caused by inventions and proposals that have something to be said for them, that are not technically impossible, and that might conceivably be of some use in some circumstances: such proposals are often pressed with great force by all sorts of influential people—scientists, Members of Parliament, and even Ministers. If we try to do all these things, we dissipate our efforts and end by doing nothing well. Someone has to decide, having all the facts in mind, what is worth doing and what is not; and the decision is not an easy one to take, and involves great responsibility. Strategical decisions in war are taken by the Cabinet on the advice of the Chiefs of Staff of the Service Departments. We may all have ideas about war strategy, but we know that the decision must be left to them. There was certainly something to be said for attacking on the Western Front some months ago, but all those who urged it must realize now what a mistake it would have been.

Who, then, is to decide the strategy of scientific war, to settle what are the things that really matter, where we are to devote our scientific strength to get the greatest

results in the shortest possible time? Certainly not scientists alone, working in the void, however eminent. Nor, in my opinion, can it be safely left to the staffs of the Fighting Services, even though each Service Department may contain officers of high scientific ability. Nor, I say, can it be left to a War Cabinet, however fertile in ideas. The safest way of reaching the right decision is to have scientists working side by side and in the closest collaboration with those who have the administrative and executive responsibility. And the first thing that the scientist learns when he has the benefit and privilege of such collaboration is that he has a lot to learn.

When the history of this war comes to be written, I hope that due credit will be given to those senior members of the staff of the Air Ministry, and to the then Minister, Lord Swinton, for adopting this policy. Since that time it has been greatly developed. The technical needs of the Royal Air Force, its staff plans, even its operations, have been submitted freely to the scrutiny and criticisms of scientists. One may safely say that good dividends have resulted, so much so that the example has spread to other Departments. But not yet enough. Let me earnesly recommend to the Parliamentary and Scientific Committee that they can do no greater service than to ensure this kind of co-operation. Let the Committee concern itself rather with the general strategy of science than with its tactics.

One last comparison before I conclude. What are the two great driving forces of our moden civilization? Science and Christianity. You may well think that is an odd, if not a preposterous, remark for a scientist to make, so I hasten to say that it is not original, and it was not first made by a scientist. When I was at school there was a youngish-looking Canon of Westminster Abbey, whose sermons were listened to even by boys, and who often had a kindly word or a smile for the small boys he passed in Dean's Yard. So when I picked up in a bookshop the other day a little volume entitled "Last Words in Westminster Abbey," by Hensley Henson, I thought that the least thing that I could do was to add a trifle to his royalties. This is what I read in one of the sermons:

> "Science and Christianity are the distinctive features of the civilization which has been cradled in Europe, and from Europe extended over the world. The principle of both is liberty, the expression, in unshackled freedom, of the innate powers of the human spirit, the expression and vindication of individuality."

Is it not of interest, especially when we recall the supposed antagonism between science and Christianity some fifty years ago, that it should be left to a leader of the Church to express, in so few and striking words, the fundamental strength of science? It set me thinking how few people see beyond the material benefits that science brings. The House of Commons seems at its best when the Whips are taken off and some subject is discussed that touches the religious life or convictions of the people they represent. In all the best social legislation Parliament is sustained and guided by the great principles of Christianity. In fact, one may say that there is hardly a member of either House of Parliament who does not understand and respect the motives and ideals of Christianity, even if he does not believe in it; whereas how few there are who understand the motives and ideals of science, even though they all believe in it. I have heard it said that this war has been brought about by the progress of science, and that it would be better for humanity if scientific research were stopped. I answer that in the past the progress of Christianity was responsible for many bloody wars: would you have stayed it for that reason? Make no mistake: this is a war of science. In these days we are witnessing how the scientific resources of Germany—and they are great indeed—are devoted to the object of destroying that intellectual freedom which is the very breath of science. So also in the Middle Ages did the Inquisition, on professedly religious grounds, strive to destroy, by the infliction of untold suffering, that liberty of conscience which is the fount of true Christianity. The tyranny of the Inquisition has long since vanished into the past, beaten down by brave men to whom death was preferable to life without freedom; who were at first disorganized and ill-equipped for the fight, and discouraged by the policy of timid Governments. So also will the present tyranny be beaten and die away, maybe sooner than we dare hope, maybe only after many years of suffering; but when it passes let us hope that scientific men, administrators, and legislators, tempered in the furnace of war, will continue to work side by side, with respect for each other's knowledge, and tolerance for each other's ignorance, to restore a stricken world and to lead us to better things.

OBITUARY.

DR. L. EDELEANU.

We take the following brief account of Dr. L. Edeleanu's life from an article by our distinguished foreign member Professor L. Mrazec in the *Moniteur Du Pétrole Roumain*, 9th April, 1941.

"During the morning of the 7th April, 1941, Dr. L. Edeleanu passed away at the age of eighty, in his home at Bucharest, in the serene evening of an existence devoted to science and to technical progress.

"The commencement of his scientific life was at the University of Berlin in the laboratories of Professors A. W. Hofmann and C. Rammelsberg, which led him to the Chemical Section of the Royal Artillery College of Woolwich, where he became the assistant of Professor Hodgkinson.

"On his return to Rumania, he was welcomed by Professor Istrati, with whom he collaborated, thence to become Director of the Chemical Laboratory of the Mines Department. In 1906, when this laboratory was taken over by the newly established Geological Institute of Rumania, Dr. Edeleanu was attached to this Institute, where he assumed the direction of the chemical work. Here very fruitful activity developed, especially in the domain of petroleum chemistry, as much by his own work as that of those whom he directed around him.

"His work and that of his collaborators bore the distinctive character of a methodical fathoming of scientific truth, which led him, amongst others, to the discovery of the important rôle which can be played by liquid sulphur dioxide as solvent and selective agent in the technology of the complex hydrocarbons contained in petroleum. This Rumanian discovery is perhaps the most important in the record of scientific and technical progress of the petroleum chemical industry. Tens of thousands of petroleum derivatives are subjected each day to the Edeleanu process in the great petroleum regions of the world—with the exception of Rumania, which, itself, should particularly require the application of this process, and whose petroleum itself gave rise to these researches.

"Of all the distinctions which have honoured Edeleanu, the Redwood medal of the Institution of Petroleum Technologists in London (1932) represents the most eminent award.

"With this distinguished scholar passes a man and a character, a jewel of Rumanian science, and an example of indefatigable and rational work, dedicated to the search for truth and the progress of science."

A. E. D.

PROFESSOR A. R. ANDREW.

The death is announced from New Zealand of Dr. Arthur Robert Andrew on 14th December, 1941, at the age of 60. Dr. Andrew was Professor of Mining at Otago University and Director of the Otago School of Mines. He was an Original Member of the Institution of Petroleum Technologists, having been elected a full Member in 1914. He retained his connection with the Institution up to 1931.

He was born and educated in New Zealand and graduated B.Sc. from Otago in 1902. Two years later he came to England, and undertook research work at the University of Birmingham. He took his M.Sc. degree in 1906 and D.Sc. (New Zealand) in 1911. For a number of years he was mineral surveyor to the Nyassaland Government, and was later employed in South America on petroleum geology. In 1914 he was appointed geologist to the Anglo-Saxon Petroleum Co. at Miri, Sarawak, and subsequently

worked at The Hague and in various European countries. In 1926 he returned to New Zealand for family reasons, and shortly afterwards was appointed to the Otago School of Mines. He was geologist for the Dominion oil-fields, and published many works on mining and geology.

In his younger days Dr. Andrew was an active Rugby footballer. He was Captain of the Birmingham University Rugby Football Club. He played for the " All-Blacks " on at least one of their tours in Great Britain. Dr. Andrew was a fine man in every sense of the word, a scientist, a sportsman, and an excellent companion. A. C.